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A MODIFICATION TO THE FREE FLOATING EXTENSIBLE CABLE SYSTEM COMPUTER MODEL (FF2E) TO CONSIDER LIFT AND DRAG FORCES ON INTERMEDIATE BODIES

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The Free Floating Extensible Cable Program (FF2E) was modified to account for velocity dependent lift and drag forces on bodies in a drifting cable system. Lift forces from a small body are shown to significantly affect the steady state geometry of a sonobuoy. The program modification allows tables of empirical lift and drag data to be input to the program and provides an interpolation scheme in a subroutine.

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SUMMARY

BACKGROUND

The FF2E two-dimensional Floating Cable Program predicts the steady state geometry of a drifting buoy system. The program assumes that bodies in the buoy suspension are point masses that generate only a horizontal drag force in a flow field. The effect on drag of body angle of attack to the flow is neglected. Vertical force at a body is only a function of body weight and buoyancy. State-of-the-art sonobuoy suspensions employ many larger and irregularly shaped bodies to improve buoy performance. In steady state conditions the relative current flow can generate lift and drag forces that significantly affect the steady state geometry of the sonobuoy, the surface float freeboard and the vertical isolation performance of the buoy. These lift and drag forces are dependent on flow velocity, angle of attack, body geometry and the location of the body in the buoy suspension.

OBJECTIVE

The objective of the task was to develop the capability to address flow related body lift and drag forces in the FF2E program. This work was performed in support of the Production Sonobuoy Support program, AIRTASK A5335330/0014/7P04000003 in conjunction with the AN/SSQ-41C development effort.

SUMMARY OF RESULTS

Empirical lift and drag force data was gathered on a sonobuoy damper disk in a flow field and compared with other forces in a typical sonobuoy. The forces were observed to vary with velocity and angle of attack and to a lesser extent with cable tension. A scheme was developed to input the lift and drag forces to the FF2E program as a two-dimensional matrix with angle of attack and velocity as the independent variables. An interpolation scheme for use with the data matrix was added to the program as subroutine BODY to minimize the impact of the modification on the existing algorithms. The modified program can accommodate 100 bodies of up to 10 different types suspended along the cable. If no lift and drag force data is input, the program operates in the same manner as before the modification was made with the exception that the input data stream is slightly modified.

The program was run with inputs for an AN/SSQ-41B mass damper sonobuoy with and without the lift and drag option. Results indicated that the lift forces were of the same order of magnitude as other forces in the suspension such as the terminal weight. The lift forces accounted for a significant change in sensor depth and cable tensions.

CONCLUSIONS

1. Flow generated lift forces on suspension components can significantly affect the steady state geometry of a drifting sonobuoy. The angle of attack, relative to the horizontal flow field, of bodies in a sonobuoy suspension have a significant effect on body lift and drag forces.

2. A modified version of program FF2E which has been brought on line at NAVAIRDEVCEN accounts for body lift and drag forces as a function of flow and angle of attack. The modification uses a look-up table approach with an interpolation scheme which lends itself to empirical data and has a negligible impact on existing algorithms.

3. The new subroutine "BODY" of FF2E is an interpolation scheme that can be adapted to other operations requiring interpolation.

RECOMMENDATIONS

1. All sonobuoy specification evaluations be performed using the updated version of FF2E to account for body lift and drag forces.

2. A technique for inputting empirical surface float data be developed that is similar to the one described in this report and that can be used with the BODY subroutine.

INTRODUCTION

As sonobuoy suspension design progresses with the state of the art, more varied and complex bodies are being included in sonobuoy suspensions. The FF2E drifting buoy computer program, described in reference (a), was developed at a time when most sonobuoys were simple drifting cable systems with spar buoy type surface floats. Modern sonobuoys typically employ inflatable complex float designs, large subsurface drogues and frequently have several significant bodies distributed throughout the suspension.

As described in reference (a), the FF2E program treated bodies in the sonobuoy suspensions as point masses. All flow induced forces were assumed to be due to horizontal drag. Vertical forces at the body were attributed only to buoyancy and weights of the body. Additionally, it was assumed in FF2E that these forces were not dependent on body angle of attack.

ANALYSIS OF BODY FORCES SONOBUOY SUSPENSION BODIES

Intermediate bodies in sonobuoy suspensions may be horizontal drag devices, vertical motion dampers, cable pack housings, hydrophones, electronics housings, or terminal weights. Three basic body types can be used to categorize the majority of bodies used in sonobuoy suspensions, i.e., rigid bodies, flexible bodies, and close coupled bodies. Rigid bodies, such as cable packs or suspension housings tend to have the most classical relationship between velocity and drag. Variations from classical drag behavior, and lift forces are introduced primarily by changes in angle of attack of the body relative to the flow. The angle of attack is governed by the drag of components below the body of interest. Flexible bodies such as those shown in figure 1 are typically used as drogues and may be either flat sheet type devices or inflatable devices. Flexible bodies tend to change angle of attack and shape as the flow velocity changes. Thus, the flexible body tends to have a nonlinear relationship between velocity and drag and lift forces. As in the case of the rigid body, the angle of attack of the flexible body has a significant effect on the lift and drag forces.

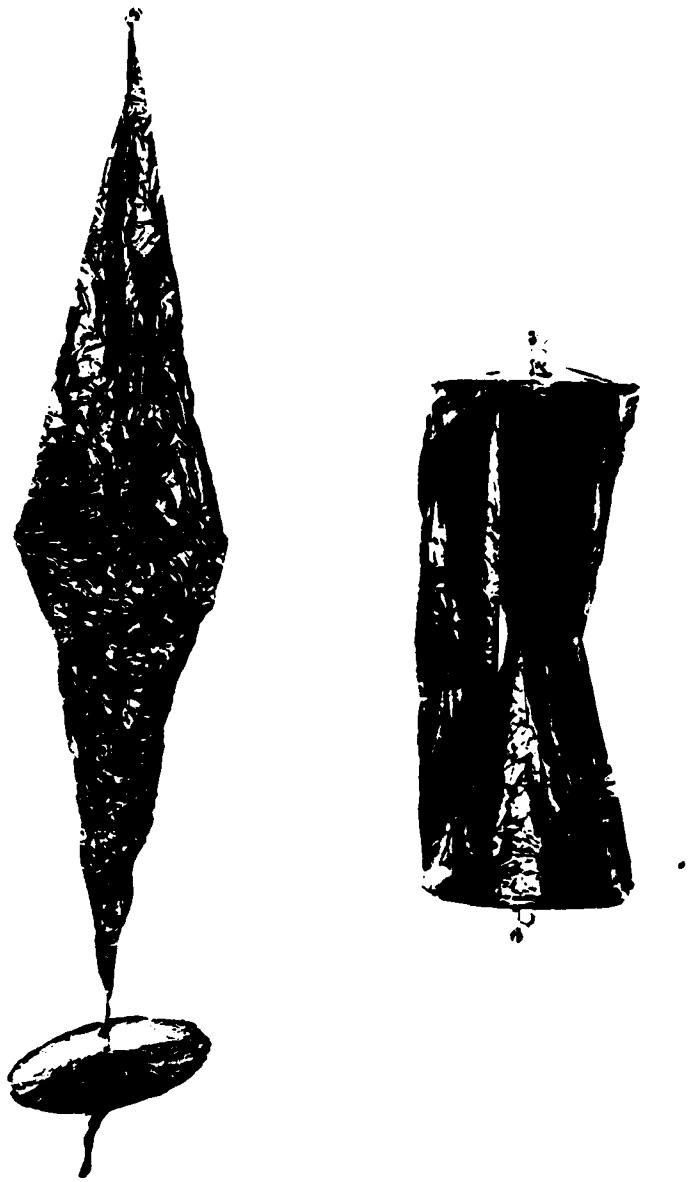

Figure 1 - Typical Flexible Bodies Used in Sonobuoy Suspensions

The hydromechanical forces on a body suspended in a cable system frequently act to pitch the body at some angle θ relative to the vertical. This pitching force is resisted by the cable tension acting through the body length. If body weight is neglected, the moments about the upper end of a suspended body in static equilibrium are represented as follows:

$$\Sigma M_A = 0 = -F_D\ (L_F \cos\theta + L_R \sin\theta)\ -F_L(L_F \sin\theta + L_R \cos\theta) + T_2 L_B \sin(\theta - \phi)$$

when

M_A = Moments about point A
F_D = Body lift force
T_2 = Cable tension below body
L_B = Body Length
L_L = Longitudinal distance along body from the upper end of the body to the point at which the hydromechanical forces act.
L_R = Radial distance from body vertical axis to the point at which the hydromechanical forces act.
θ = Angle of body longitudinal axis to vertical.
ϕ = Angle of cable below body relative to vertical.

The system represented by equation (1) is shown schematically in figure 2. An inspection of equation (1) indicates that as the body length decreases the angle $(\theta - \phi)$ must become larger to maintain the same moment. Thus, long bodies will be essentially aligned with the cable whereas for short bodies (close coupled bodies) the angle $(\theta - \phi)$ will be significant and will vary inversely as the cable tension. Thus, for close coupled bodies the lift and drag forces will be a function of the flow velocity, angle of attack and cable tension.

DISCUSSION OF VARIABLES

As indicated above, the independent variables in the body force problem are velocity, angle of attack and cable tension. Velocity is a function of the current profile and the overall geometry of the cable suspended system. As the FF2E model converges on a solution a given body in the model will be subjected to a number of different velocities. Angle of attack, primarily a function of the current velocity profile and the system geometry below the body of interest, will also vary as the FF2E model iterates toward a solution. Similar bodies located at different points in a suspension can experience different angles of attack. Cable tension generally is not as variable as the other two parameters and can be easily predicted. In addition, it has been shown that cable tension is not a significant factor in the variability of angle of attack on long bodies.

LIFT AND DRAG FORCE MAGNITUDE

A series of tow tests was performed on a typical sonobuoy body, a twelve inch diameter damper disk, to measure the lift and drag forces as a function of velocity. Data from this test was processed to yield tables of forces for lift and drag as functions of velocity and body angle of attack. Although the disc is a close coupled body, cable tension variations were ignored in the experiment. A summary of this effort is presented in appendix A. Tables AI and AII are the

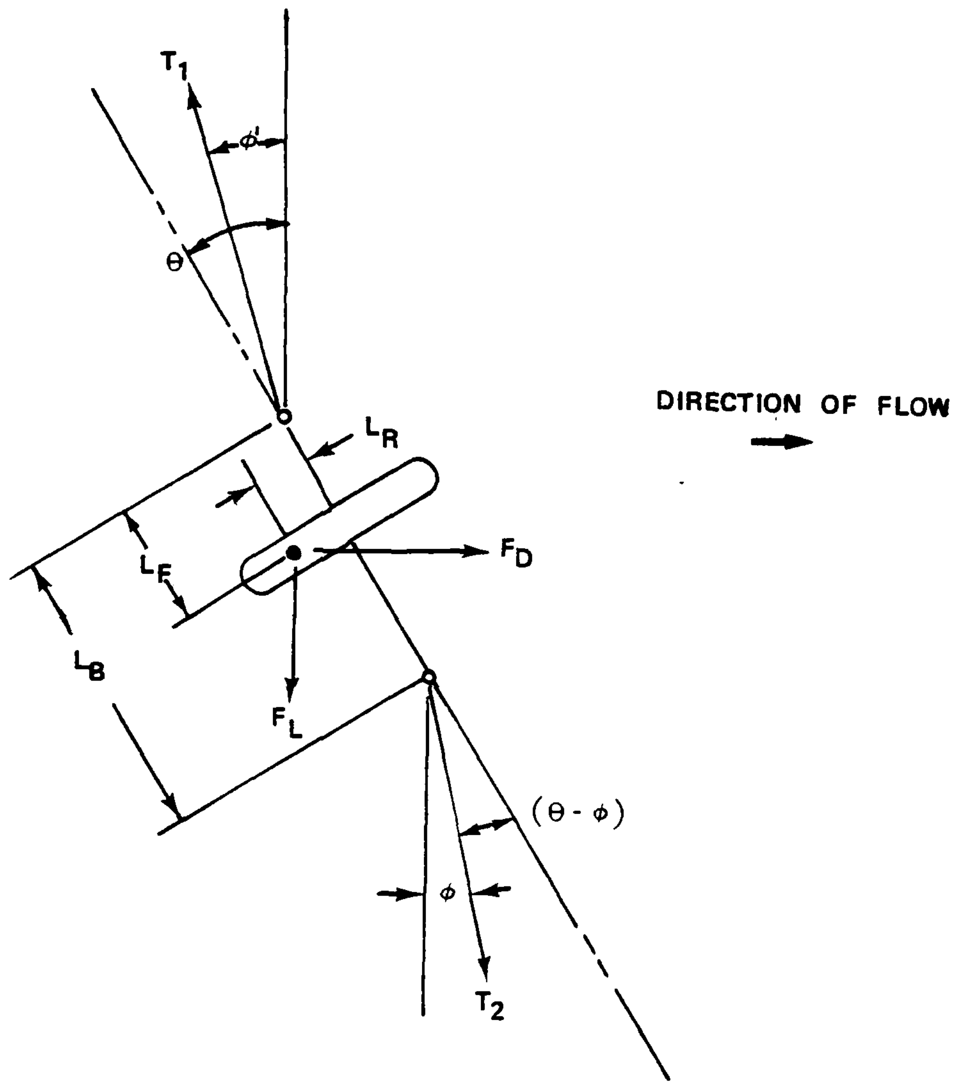

Figure 2 - Forces on a Closed Coupled Body Neglecting Body Weight

tables of lift and drag forces, respectively, for the 12 inch damper disc with respect to flow velocity and angle of attack. Angle of attack, in this case, is the angle of the suspension cable from vertical since the effect of cable tension on the disc coupled body was ignored.

As indicated in the table, lift forces can be generated from the disc up to values as high as 0.53 pounds. (Note that the negative signs in the table indicate the lift force is downward.) In a typical AN/SSQ-41B sonobuoy, the terminal weight is of the order of 0.5 to 0.7 pounds. Thus, the lift forces are of the same order as the body weight forces and can be expected to have a significant effect on the steady state geometries of the buoy. Similarly, as indicated in table AII, the drag force on the disc can vary with angle of attack as much as 0.6 pounds at a constant velocity. Again, this variation of force is of the order of the other significant forces in a typical sonobuoy and can be expected to have a significant effect on the steady state geometry of the system. In addition, freeboard of the surface float and spring constant of the compliance in buoys such as the SSQ-41B can be significantly affected by force variations of the magnitude shown herein.

FF2E PROGRAM MODIFICATION APPROACH

The FF2E program treats bodies in the cable system as forces acting on the cable, a horizontal force representing drag and a vertical force representing wet weight or net buoyancy. The modification incorporated into FF2E to account for lift and variable drag forces accepts data in the form of tables of forces, similar to tables AI and AII. This facilitates the input of empirical data and can accommodate nonlinear systems with no added complexity. The independent variables on the tables are angle of attack and velocity in knots. The dependent variables are lift force and drag force. Cable tension is not considered.

The FF2E program calculates forces on the system from the upper end of the cable downward. When it reaches a body, the value of the cable angle relative to vertical and the relative velocity at that point are used to select the appropriate lift and drag force from the table. Interpolation inside or outside the table is performed in subroutine BODY. Additionally, in subroutine BODY, the lift force value from the table is subtracted from the weight of the body and the drag force is used to compute a new body drag over (C_DA). The resultant C_DA and body weight are then inserted into the approximate equation in subroutine STEADY and the calculation of forces continues down the next cable segment.

CAPABILITIES OF THE MODIFIED PROGRAM

The FF2E program retains the original capability of the FF2E program to handle up to 100 cable segments and bodies. For each body in the system having variable drag and lift inputs, a table may be input to the program up to a maximum of 10 tables. If a body occurs multiple times in a suspension the same table may be used each time. Table dimensions may be from one to seven angles and from one to ten velocities. If a body does not have a lift and drag data table, single values for C_DA and weight are input as in the original FF2E program the BODY subroutine is ignored. If no lift and drag tables are input, the program runs in the same manner as the unmodified FF2E.

As an incidental change, the cable volume factor (CVFAC) parameter format was modified so that an individual CVFAC may be input for each cable segment.

A complete listing of the modified FF2E program is available from NAVAIRDEVCEN, Code 3043.

SAMPLE RESULTS

COMPARISON OF RESULTS WITH AND WITHOUT LIFT/DRAG TABLE

A simple extensible cable type drifting system having a horizontal disc near the terminal body was modeled on the FF2E program with and without the lift/drag modifications. A sketch of the system is shown in figure 2. The significant input parameters are listed in table I.

TABLE I

SIGNIFICANT INPUT PARAMETERS FOR FF2E FOR A SIMPLE DRIFTING CABLE SYSTEM WITH A DAMPING DISC AT THE TERMINAL BODY

Cable Segment	Type	Length (Feet)	Diameter (Inches)
1	Compliant	60	0.055
2	Noncompliant	940	0.081

Surface float drag area 1.14 ft^2
Terminal body (excluding damper disc)
Weight 0.5 lb
Drag Area 0.62 ft^2

CURRENT PROFILE - RESOC 90% (Reference (b))

Depth (Feet)	Current Velocity (Knot)
0	1.85
40	1.14
100	0.96
200	0.78
1000	0.34
2000	0.20

The weight and edge-on drag area of the disc were considered negligible and indeed were found empirically to be insignificant relative to other forces in the system.

A comparison of the results of the two models is listed in table II. As indicated in the table, the lift forces from the disc hold the terminal weight at a deeper depth and increase the cable tension by approximately 25 percent.

TABLE II

COMPARISON OF THE RESULTS OF FF2E MODELS WITH AND WITHOUT LIFT AND DRAG FORCES

Result	No Lift	Velocity Dependent Lift and Drag Included
Terminal Body Depth (feet)	482.84	554.34
Cable Angle At Terminal Body (degrees)	60.1	43.9
Max Cable Tension (lb)	1.00	1.27
No. of Iterations to Solution	72	29
Lift Force at Disc (lbs) (Positive Upward)	N/A	-0.42
Drag Force at Disc (lbs)	N/A	0.85
Relative Velocity at Terminal Body (knot)	0.66	0.64
Drift Velocity (knot)	1.20	1.14

Thus, a significantly different system geometry is predicted when the velocity dependent forces on the disc are considered.

The lift and drag data from the disc was input to the program in various table sizes to determine the effect on convergence and the quality of the solution. The various input table sizes and corresponding results are shown in table III. In general, if the 40° disc angle data was present in the table, a solution was quickly reached. In the 4 x 2 table only 5° and 30° values were included and convergence did not occur. Thus, it appears that while table size is not an overriding criteria, it is advantageous to bracket or at least approach the expected angles and velocities with the data table to assure convergence.

TABLE III

TABLE OF INPUT DATA, TABLE SIZES AND CORRESPONDING RESULTS

No. of Table Points Velocity	Angle	No. Iterations	Forces (lb) Lift	Drag	Terminal Wt Depth (ft)	Max Tension (lb)	Angle At Body
6	7	29	-0.416	0.850	554.34	2.37	43.71
5	6	29	-0.416	0.850	554.31	2.37	43.93
4	4	30	-0.418	0.849	554.65	2.37	43.77
4	3	37	-0.383	0.833	549.42	2.34	44.48
4	2*	401**	-0.535	0.720	586.93	2.46	34.10
4	1***	60	-0.475	0.833	562.74	2.41	41.94
No Table		79			482.84	2.02	60.06

* Table angles were 5° and 30°. Table did not bracket the solution.
** Program stops after 401 iterations regardless of convergence.
*** Angle = 40°.

LIFT/DRAG DATA TABLE GENERATION

A lift and drag force table may be generated empirically by towing a body at appropriate velocities while holding the body angle of attack fixed and measuring the lift and drag forces. The procedure can then be repeated for a number of angles of attack as required. A text fixture for obtaining these measurements is under development at the Naval Air Development Center.

If lift and drag data are obtained from tow test of a tethered body at various velocities with no control on the angle of attack, a single column table may be used. There should however, be some correlation between the predicted angles of attack of the body and the angles of attack measured at the body during the tow testing.

INPUT DATA FORMAT

An annotated list of the input and output parameters of the FF2E Fortran IV program incorporating subroutine BODY is presented below. Included are instructions for either including or omitting the velocity dependent lift/drag force table and interpolation schemes. This list is intended as a user reference manual. A complete explanation of the program is included elsewhere in this report and in reference (a).

The input parameters are listed by card and column numbers as they appear on the FF2E input file in the NAVAIRDEVCEN Acoustic Development Division program library. Each parameter name is the Fortran IV variable name used in the program.

Card 1

Column 1 to 3

1. NCASES - number of "cases" or sets of parameters to be analyzed. A typical set of parameters is fully described by variables 2 through 39. NCASES may only be listed once at the beginning of the data deck. For situations involving more than one "case," list parameters 1 through 39 for the first case and 2 through 39 for each succeeding case. NCASES is an integer.

Card 2

Column 1 to 3

2. ISTOP - dummy label for operator's use only. This is the number labeling the ith case. (i.e., for the second case (ISTOP=2) ISTOP is an integer.

Column 4 to 6

3. NCUR - number of current profile points. (i.e., the number of values listed under variables 32 and 33 below) NCUR is an integer. Maximum number of current points is 30.

Column 7 to 9

4. NCAB - number of cable segments involved in the system to be analyzed. A cable segment is a length of cable whose phy physical characteristics are constant and which is bounded by either endpoints (i.e., top or bottom of cable) or other system components such as drogues, hydrophones, etc. If the cable properties change, the cable segment ends and a new one begins. NCAB is an integer.

Column 10 to 12

5. NHPHS - number of hydrophones. This is a dummy label for the operator's use only. NHPHS is an integer.

Column 13 to 15

6. NTAB - number of lift/drag forces tables. If no tables are used NTAB=0. NTAB is an integer.

Card 3

Column 1 to 12

7. DAI - diameter of surface buoy antenna in inches. DAI is a floating point number.

Column 13 to 24

8. LA - Length of surface buoy antenna in feet. LA is a floating point number.

Column 25 to 36

9. CDA - drag coefficient in air for surface buoy antenna. This is a floating point number.

Column 37 to 48

10. TBH - horizontal component of tension applied to lower unit.

Column 49 to 60

11. TBV - vertical component of tension applied to lower unit. The horizontal and vertical components of tension in pounds applied just below the bottom unit are of interest in cable payout problems. For free-floating systems, TBH=TBV=0.0. TBH and TBV are floating point numbers.

Card 4

Column 1 to 12

12. DB - diameter of cylindrical surface buoy in feet. DB is a floating point number.

Column 13 to 24

13. LB - length of cylindrical surface buoy in feet. LB is a floating point number.

Column 25 to 36

14. CDB1 - drag coefficient in water of cylindrical surface buoy for portion of buoy submerged. CDB1 is a floating point number.

Column 37 to 48

15. CDB2 - drag coefficient in air of cylindrical surface buoy for portion of buoy above sea surface. CDB2 is a floating point number.

Column 49 to 60

16. WB - weight of surface buoy in air in pounds. WB is a floating point number.

Column 61 to 72

17. UWINDK - velocity of wind in knots. UWINDK is a floating point number

Card 5

Column 1 to 12

18. CDAPK - drag area of a package hung just below the surface buoy. CDAPK=C_d. Area, where Area is the cross section of the package presented to the current in square feet. CDAPK is a floating point number.

Column 13 to 14

19. WPAK - weight in water in pounds of a package hung just below the surface buoy. WPAK is a floating point number.

NOTE: For variables 20 thru 31, a value is read in for each cable segment K where K = 1 through NCAB.

Card 6

Column 1 to 12, 13 to 24, etc.

20. FLC(K) - length of each cable segment in feet. The number of cable segments is listed in parameter four above. Each cable segment length must be specified in numerical order from top to bottom. They must also be printed out in each successive 12 space block on the data cards. If there are more than six cable segment lengths to be specified continue on additional cards. Only use six lengths per card. FLC is a floating point number.

Card 7

Column 1 to 3, 4 to 6, etc.

21. NPR(K) - number of points along each cable segment for which an answer is to be printed out. This is left to the judgement of the operator. NPR is an integer. Each value of NPR associated with its corresponding FLC must be specified in numerical order from top to bottom just as FLC. Each NPR must be specified in successive three space blocks on the data cards. If additional space is required, use as many extra cards as necessary. Use only 72 spaces (or 24 blocks) per card.

NOTE: The following data points are all listed in numerical order from top to bottom and are listed in successive 12 space blocks on the data cards. A maximum of six blocks per card is allowed for all parameters. As many additional cards as necessary may be used. The only requirement is that the number of points printed on cards correspond to the number of points specified in either parameter three (NCAB) or four (NCUR), whichever is appropriate.

Card 8

Column 1 to 12, 13 to 24, etc.

22. DCI(K) - diameter of cable in inches. DCI is a floating point number.

Card 9

Column 1 to 13, 13-14, etc.

23. CVFAC - conversion factor for noncircular cross section cable. Maximum cable diameter must be specified in the program for cable drag calculation purposes. This however, is not satisfactory for cable buoyancy calculations since it implies the cable displaces more water than it actually does

for noncircular cable. CVFAC may be calculated either by use of buoyancy considerations or by geometric means.

Buoyancy + Air Weight = $\ell \rho g (CVFAC) \pi r^2$

Buoyancy = buoyant force measured by immersing cable sample in water

Air Weight = weight of cable in air

ℓ = length of cable sample
ρ = density of water
g = 32 ft/sec^2
r = radius of cable ($\frac{DCI\ (K)}{2}$ inches)

or by geometric considerations;
Real Cross sectional Area = (CVFAC) πr^2
CVFAC is a floating point number.

Card 10

Column 1 to 12, 13 to 24

24. WC(K) - weight of cable in water per unit length in pounds per foot. WC is a floating point number.

Card 11

Column 1 to 12, 13 to 24, etc.

25. CDC(K) - coefficient of drag of cable segment normal to the cable. CDC is a floating point number.

Card 12

Column 1 to 12, 13 to 24, etc.

26. TREF - reference tension on cable segment (K). This is the tension required to maintain a cable at its specified length, FLC. It is most significant on compliant cable segments. If FLC is the unstretched or unloaded cable length or if the change of cable length is insignificant with the application of a load, TREF (K) may be set equal to zero. Note that if some TREF is specified, and the calculated load is less than TREF, the integration process will shrink the length of the cable segment from what is specified in FLC. TREF is a floating point number. TREF is in units of pounds.

Card 13

Column 1 to 12, 13 to 24, etc.

27. P(K) - poisson's ratio for each cable segment. P is a floating point number.

Card 14

Column 1 to 12, 13 to 24, etc.

28. AE(K) - product of the cross sectional area and elastic modulus for each cable segment. AE must be determined experimentally for loads close to those which the system will experience while deployed.

$$AE = \frac{\ell_o T}{\Delta \ell}$$

where

T = load (lb)

ℓ_o = unstretched cable length

$\Delta \ell$ = change in length while under load

If a TREF is specified

$$AE = \frac{\ell_o (T - TREF)}{\Delta \ell}$$

AE is a floating point number. AE is in units of pounds.

Card 15

Column 1 to 12, 13 to 24, etc.

29. CDABD(K) - drag area (i.e., $C_d \cdot$ Area) of a body at the end of each cable segment. If there is no body, CDABD=0.0 CDABD is a floating point number. DCABD is in units of square feet.

NOTE: If a lift table is specified for a body, i.e., if NBOD = 0 the value of CDABD(K) printed in the program output is calculated from the average of the drag forces in the corresponding drag table.

Card 16

Column 1 to 12, 13 to 24, etc.

30. WBD(K) - weight in water in pounds of a body at the end of each cable segment. Each WBD has a corresponding CDABD. If there is no body, WBD=0.0. WBD is a floating point number.

Card 17

Column 1 to 3, 4 to 6, etc.

31. NBOD(K) - lift/drag force table number which applies to the body at the lower end of cable segment K. If no table is specified NBOD(K) = 0. NBOD(K) is an integer.

NOTE: For variables 32 and 33, a value is read in for each current point I where I = 1 through NCUR.

Card 18

Column 1 to 12, 13 to 24, etc.

32. XX(I) - depth of each current point in feet, starting from the surface and going down. XX is a floating point number.

Card 19

Column 1 to 12, 13 to 24, etc.

33. YY(I) - current velocity at each current point in knots, corresponding to each XX, starting from the surface and going down.

NOTE: Cards 20 through 24 form a complete lift and drag force table. For each table cards 20 through 24 should be input in sequence, (e.g., 20, 21, 22, 23, 24, 20, 21, 22, 23, 24, etc.). The first table will be applied to bodies where the value of NBOD is 1, the second table in the sequence will be applied to bodies where the value of NBOD is 2 and so forth. If no lift and drag force tables are used, i.e., NTAB=0, then cards 20 through 24 may be omitted.

For variables 34 through 37, N=1 through NTAB, I = 1 through NPHI (N) and J=1 through NU (N).

Card 20

Column 1 to 3

34. NPHI(N) - number of angle values for which lift and drag forces are tabulated.

(NPHI(N) and NU(N) are integers.)

Card 21

Column 1 to 12, 13 to 24, etc.

36. PHIM(N,I)-angle in degrees of suspension cable from vertical for which body lift and drag forces are tabulated.

Card 22

Column 1 to 12, 13 to 24, etc.

37. U(N,J) - velocity in knots for which body lift and drag values are tabulated. PHIM (N,J) and U(N,J) are floating point numbers. For variables 38 and 39, M=1 to NP, where NP=NU(N). NPHI(N) i.e., the total number of lift or drag data points in table N.

Card 23

Column 1 to 12, 13 to 24, etc.

38. DDRAG(M) - Drag value in pounds for a velocity and angle.

Card 24

Column 1 to 12, 13 to 24, etc.

39. DLIFT(M) - Lift value in pounds for a velocity and angle. Lift is positive upward. DDRAG(M) and DLIFT(M) are floating point numbers.

FF2E PROGRAM OUTPUT

FF2E is designed to print out all data referring to initial buoy configuration. All of these are self explanatory.

While going through the iteration process, the result of each individual calculation is tabulated. The values which are printed are:

Drift (kn)	- drift of surface buoy in knots
Draft (ft)	- draft of surface buoy in feet
Drag (Bot)	- drag on bottom of cable
Wt (Bot)	- weight plus lift forces on terminal body
Error (Hor) Error (Vert)	- horizontal and vertical errors of forces at the end of each calculation. Run is finished when these are approximately zero.
Ten (Bot)	- tension in cable at bottom of surface package
PHI (Bot)	- angle of cable at bottom measured from horizontal
TZEROX	- horizontal component of tension at the surface float
TZEROY	- vertical component of tension at the surface float
DELTA	- a constant used in calculations

After the run is finished, the final calculation is printed out. This includes:

SREF (ft)	- unstretched cable reference length
SSTR (ft)	- stretched cable length
X (ft)	- horizontal displacement of cable point
Y (ft)	- depth of cable point
PHI (deg)	- angle of cable relative to horizontal
T (lb)	- tension in cable (lb)
PHIV (deg)	- angle of cable relative to vertical
CREL (kn)	- relative current velocity in knots at cable point

LIFT(lb) - body lift force in lb as interpolated from tabulated data. If no table is used "BODY NUMBER N, NO LIFT" is printed.

DRAG(lb) - body drag force in lb as interpolated from tabulated data. If no table is used no value in printed.

REFERENCES

(a) Wang, Henry T., and Moran, Thomas L., "Analysis of the Two-Dimensional Steady-State Behavior of Extensible Free Floating Cable Systems," NSRDC Report No. 3721, Oct 1971

(b) Holler, R. A., "Ocean Current Profile Definition," Research on Sonobuoy Configuration Annual Report 1976, PP 109-151, Naval Air Development Center, 1 Sep 1977

APPENDIX A

MEASUREMENTS OF VELOCITY DEPENDENT LIFT AND DRAG FORCES ON A SONOBUOY DAMPING DISC

OBJECTIVE

The objective of this effort was to measure lift and drag forces as a function of velocity and angle of attack on a twelve-inch diameter packageable sonobuoy damper disc.

TEST PROCEDURE

The disc was suspended at the end of an eight-foot long line which was attached to tilt and tension sensors aboard the NAVAIRDEVCEN open water facility tow carriage. The sensors measured tension in the line and angle of the tow line from vertical. Sensor outputs were read out on a strip chart recorder. The disc was towed at 0.1, 0.2, 0.29, 0.39, 0.5 and 0.6 knots. The tow series was repeated with different terminal weights to provide data at more than one angle for each velocity point.

RESULTS

The tension and angle data were resolved into lift and drag forces by application of equations (A1) and (A2).

$$\text{Lift} = W - T\cos\theta \qquad \text{(A1)}$$

where

θ = angle of the cable from vertical
W = weight of suspended body
T = cable tension

$$\text{Drag} = T\sin\theta \qquad \text{(A2)}$$

Data points for lift and drag forces were plotted for each velocity as shown in figures A-1 and A-2. Where necessary the curves were extrapolated such that data could be read off at cardinal angles of 1, 5, 10, 20, 30, 40 and 50 degrees. These points were used to form the lift and drag force data tables used in the modified FF2E program. These tables are included as tables AI and AII.

TABLE AI
LIFT FORCES IN POUNDS VERSUS ANGLE AND
VELOCITY FOR A 12 INCH DISC

Velocity (Knot)	Angle (Degrees) 1°	5°	10°	20°	30°	40°	50°
0.10	0	0	0	0	0	0	0
0.20	0.05 lb	0	0	0	0	0	0
0.29	0.16 lb	-0.175 lb	-0.299 lb	-0.295 lb	-0.240 lb	-0.120 lb	+0.140 lb
0.39	0.18 lb	-0.105 lb	-0.251 lb	-0.320 lb	-0.273 lb	-0.150 lb	+0.080 lb
0.50	-0.080 lb	-0.245 lb	-0.352 lb	-0.370 lb	-0.345 lb	-0.255 lb	-0.025 lb
0.60	-0.15 lb	-0.270 lb	-0.360 lb	-0.465 lb	-0.535 lb	-0.475 lb	-0.325 lb

TABLE AII
DRAG FORCES IN POUNDS VERSUS ANGLE AND
VELOCITY FOR A 12 INCH DIAMETER DAMPER DISC

Velocity (Knot)	Angle (Degrees) 1°	5°	10°	20°	30°	40°	50°
0.10	0	0	0	0	0	0	0
0.20	0.019 lb	0	0	0	0	0	0
0.29	0.270 lb	0.075 lb	0.100 lb	0.133 lb	0.133 lb	0.133 lb	0.133 lb
0.39	0.085 lb	0.146 lb	0.183 lb	0.240 lb	0.259 lb	0.266 lb	0.266 lb
0.50	0.170 lb	0.260 lb	0.320 lb	0.410 lb	0.480 lb	0.520 lb	0.533 lb
0.60	0.233 lb	0.313 lb	0.400 lb	0.563 lb	0.720 lb	0.833 lb	0.876 lb

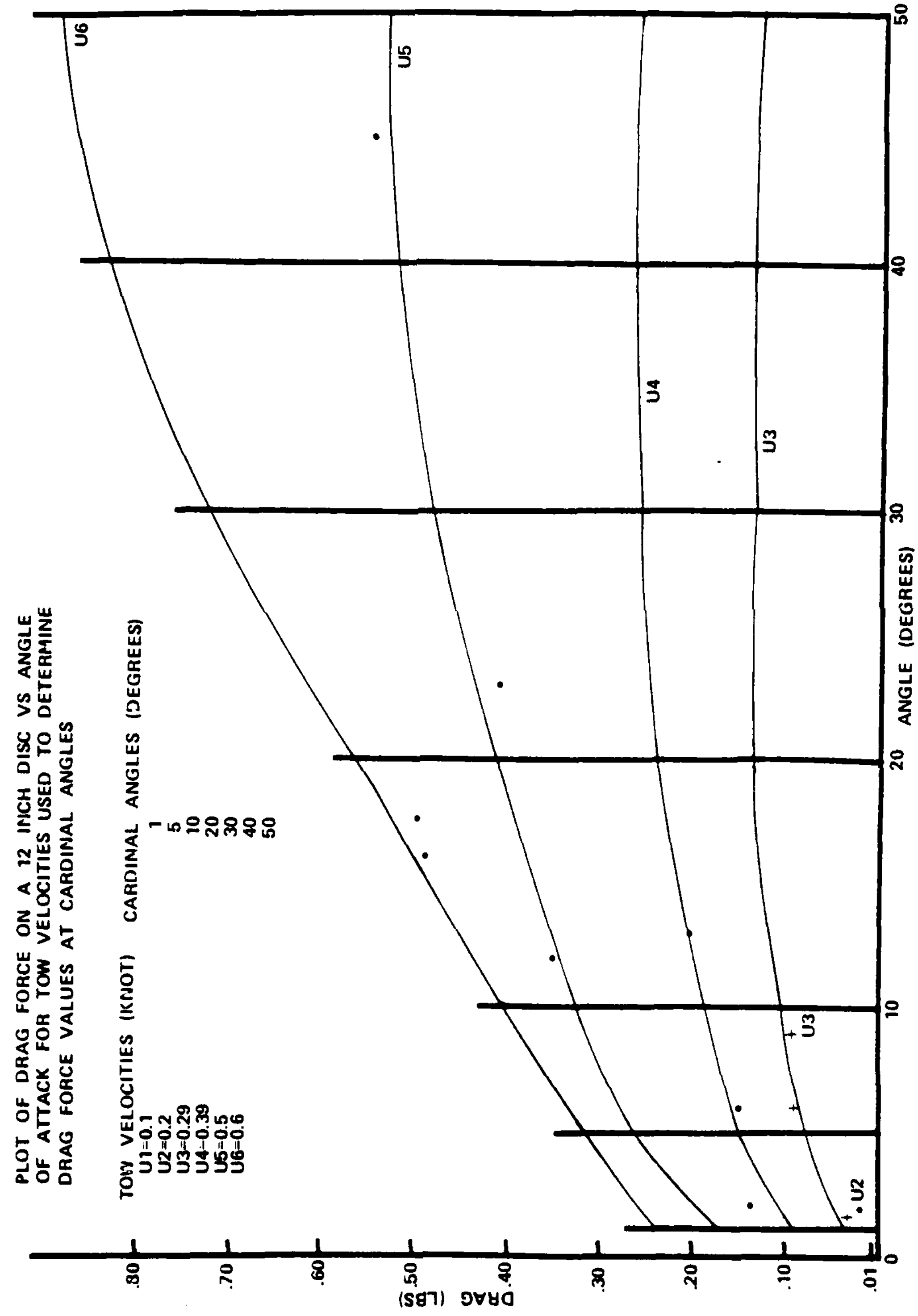

Figure A1 - Typical Flexible Bodies Used in Sonobuoy Suspensions

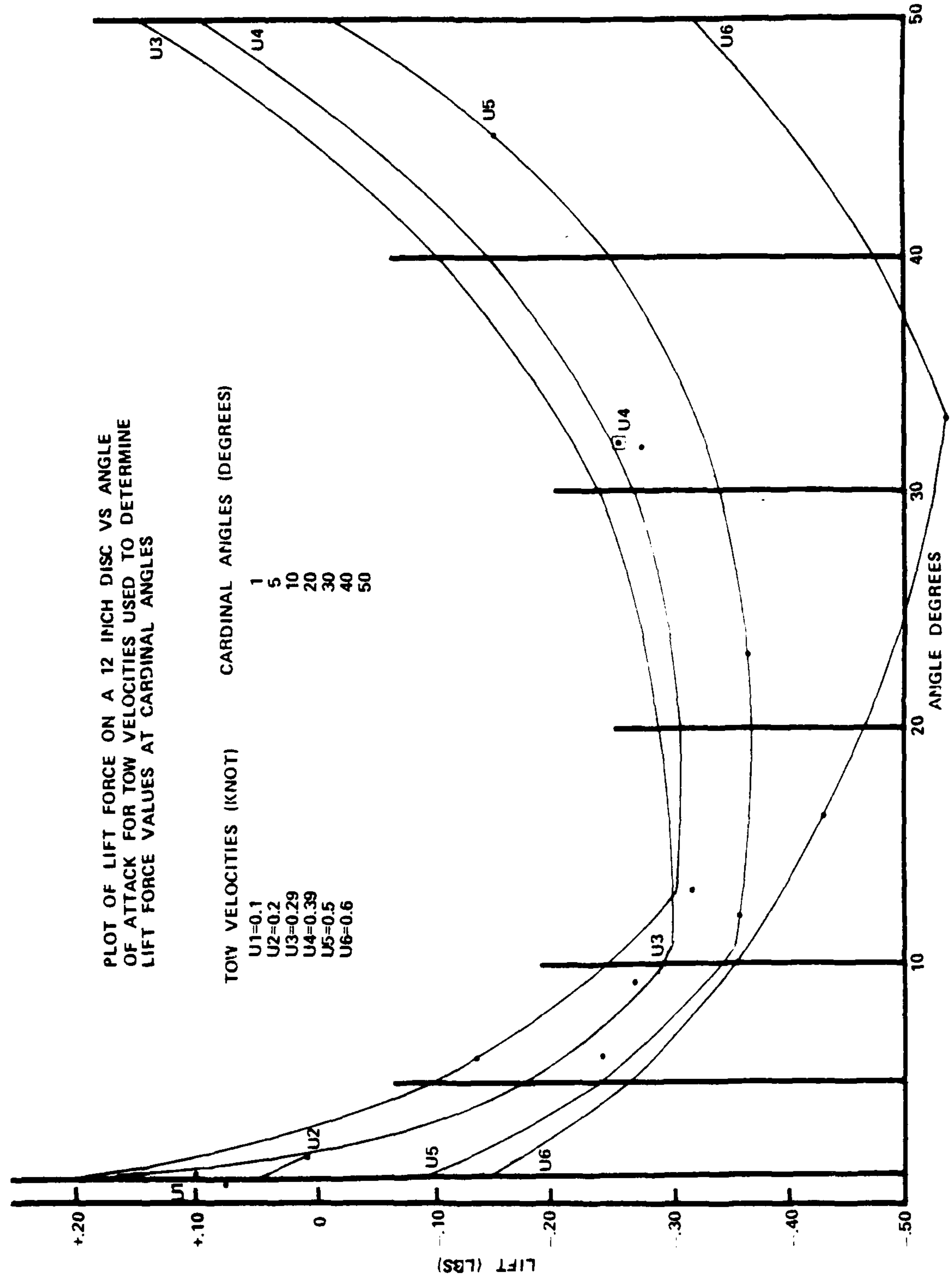

Figure A2 - Forces on a Close Coupled Body Neglecting Body Weight

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